Fine structure of Si-vacancy spin qudits in silicon carbide

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The vacancy-related spin centers in silicon carbide (SiC), a material compatible with Si-MOS technology, are promising for the realization of sensors and quantum information devices. The silicon vacancy (V_{Si}) in SiC possesses the half-integer spin 3/2; its spin states can be selectively initialized and read-out by optical means and efficiently manipulated by a radiofrequency (RF) field [1-4]. The high half-integer spin of the Si vacancy provides additional degree of freedom and functionality.

Here, we discuss the fine structure of V_{Si} centers in zero and external magnetic fields, which is a key to understanding the spin dynamics and relaxation processes. We show that the C_{3v} point group of the V_{Si} center imposed by the real atomic arrangement of the vacancy gives rise to additional terms in the spin Hamiltonian, which are absent in axial models. Particularly, the trigonal pyramidal symmetry of the V_{Si} center enables the ``forbidden'' RF field-driven spin transitions with a change in the spin projection $\Delta m = \pm 2$ ($\nu_3$ and $\nu_4$ lines in Fig. 1). As compared to the commonly studied ``allowed'' spin transitions with $\Delta m = \pm 1$ (ν_1 and ν_2 lines in Fig. 1), they are induced by counter circularly polarized radiation and their energies shift with the double slope in the magnetic field. Comparison with the experimental data on optically detected magnetic resonance (ODMR) allows us to determine the parameters of the spin Hamiltonian [5].

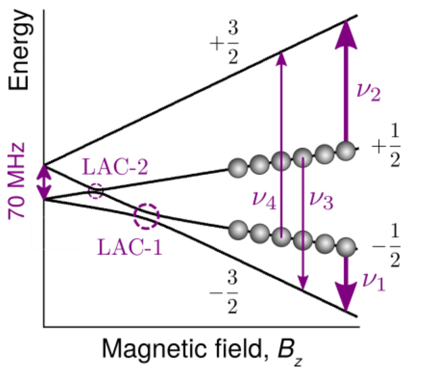

Fig. 1. Spin structure of the V_{Si} center in magnetic field. Vertical arrows denote ``allowed'' ($\nu_1$ and $\nu_2$) and ``forbidden'' (ν_1 and ν_2) transitions.

In an external magnetic field, the otherwise degenerate sublevels $m = \pm 1/2$ as well as $m = \pm 3/2$ split and, at certain fields, one observes the level anticrossings (LACs in Fig. 1): LAC-1 between the states with $\Delta m = 1$ and LAC-2 between the states with $\Delta m = 2$. The intensity of photoluminescence demonstrates resonance-like behavior in the vicinity of the LACs. The sharpest resonance is detected for the level anticrossing with $\Delta m = 2$, determined by the parameters related to the trigonal pyramidal symmetry of the V_{Si} center. This phenomenon can be used for a purely optical sensing of dc magnetic fields, without a need for the application of a RF field, with nanotesla resolution [5]. The effect is robust up to at least 500 K, suggesting a simple, contactless method to monitor weak magnetic fields in a broad temperature range. The proposed method can potentially be extended to RF-free sensing of other physical quantities, particularly, temperature and axial stress.

References

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